BIOLUMINESCENCE AND OPTICAL VARIABILITY IN THE SEA ('MARINE LIGHT - MIXED LAYERS'): MOORED OBSERVATIONS IN THE NORTH ATLANTIC OCEAN

by C. Ho, C. Langdon, M. Maccio, J. Marra

LDEO TECHNICAL REPORT
LDEO-97-1

Department of the Navy
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Lamont-Doherty Earth Observatory of
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1. Guide to Figures with Captions

2. INTRODUCTION

The Marine Light - Mixed Layers mooring was deployed south off Iceland at 59°35.6'N/ 20°57.9'W, from April 29 (day 119) to September 06 (day 249),1991. The subsurface moored array included five Multivariable Moored Sensors (MVMS). This report discusses data collected by three MVMS, deployed at 30 m,70 m and 90 m, and designed, prepared and implemented by LDEO. The two others were deployed by the Ocean Physics Group of the University of Southern California.

2.1 Record Format

All signals from sensors were processed by a TATTLETALE model 6 computer and results were stored in a hard-disk as ASCII files. Records were put into files every 128 second. Each record contains 13 fields: SAMPLE number, DATE, TIME, FLUorometer, TEMperature, CONductivity, PAR, TRAnsmissometer, LU683, VOLtage, electrical CURRent, Dissolved Oxygen, dissolved oxygen temperature and VMCM readings. A typical record is shown below:

```
SAMPLE:00009900   DATE:05/08/91 TIME:03:51:04 FLU:1160 TEM:06720
CON:08856 PAR:0200 TRA:4250 683:0361 VOL:1391 CURR:0031 DO:0F8E
17DC              VMCM:     F014B8BCFF0B7F0B8FBCBF00040710
```

Except for the date, time and VMCM readings, all numbers are in decimal format.

3. SENSOR CALIBRATION CONSTANTS

3.1 Stimulated Fluorescence

Calibration of all the fluorometers was done according to Marra and Langdon (1993). The formula used was:

$$\text{Chlorophyll (mg m}^{-3}\text{)} = \text{mchl} * \text{FLU} + \text{bchl}$$

Table 1 shows the values of the constants in the equation.

3.2 Water Temperature

There were three temperature sensors on each system. The first one is part of the VMCM. Raw data from this sensor is recorded as a hexadecimal number at character 23-26. The calibration formula is:

$$R = A0 * (A1 - TEM)/(A1 + TEM)$$

$$\text{Temperature}(^{\circ}C) = 1/(AT+BT*\ln(R)+CT*(\ln(R))3)-273.15$$

The calibration coefficients are in Table 2

The second sensor was a SeaBird thermistor. For these, temperature was calculated using the formulas:

$$R = A0 /TEM$$

$$\text{Temperature}(^{\circ}C) = 1/(AT+BT*\ln(R)+CT*(\ln(R))2+DT*(\ln(R))3)-273.15$$

Temperature Calibration coefficient are in Table 3.

The third temperature sensor was part of the Endeco oxygen sensor. The data was recorded as the second number after the symbol 'DO'. The formula used for calibration were:

$$R = A0 * A1 *TEM$$

$$\text{Temperature}(^{\circ}C) = 1/(AT+BT*\ln(R)+CT*(\ln(R))3)-273.15$$

The calibration coefficients are listed in Table 4.

Table 1: Fluorometer Calibration Coefficients

depth	SN	mchl	bchl
30	95	2.03427	-0.13423
70	131	1.62773	-0.13631
90	6	1.51379	-0.15076

Table 2: VMCM Thermistor Calibration Coefficients

depth	SN	A0	A1	AT x 10^3	BT x 10^4	CT x 10^7
30m	401405	54.363	9770.8	2.48957	2.50563	3.32480
70m	500201	54.429	9763.8	2.48825	2.50808	3.24351
90m	203103	54.437	9753.5	2.47808	2.49595	3.37585

Table 3: SBE Thermistor Calibration Coefficients

depth	SN	A0	AT x 10^3	BT x 10^4	CT x 10^5	DT x 10^6
30m	1091	5587.77	3.67450	4.84929	1.39351	2.38826
70m	1090	5484.63	3.67450	5.85315	1.40090	2.32984
90m	1134	5498.80	3.67443	6.03421	1.56514	3.40006

Table 4: Endeco Thermistor Calibration Coefficients

depth	SN	A0	A1	ATx10^3	BTx10^4	CTx10^7
30m	48	8168.1	-0.81791	1.55798	2.21910	1.81005
70m	49	8161.6	-0.81714	1.56222	2.21049	1.86478
90m	50	8163.18	-0.8168	1.56739	2.20225	1.88796

3.3 Conductivity

Conductivity was calculated using the Sea-Bird formula

$$Conductivity(mmho/cm) = a * CON^m + b * CON^2 + c + d * T$$

where b, c, d and m are calibration constants for each sensor, and T temperature in ^oC.

Constants for conductivity calculation:

Table 5: SBE Conductivity Sensor Calibration Coefficients

depth	SN	a x 10^5	b x 10	c	d x 10^5	m
30m	356	0.009395	4.18736	-4.17797	0.98150	5.9
70m	839	1.16682	5.23405	-4.06373	-4.83262	4.3
90m	840	1.85552	5.84570	-414960	-5.07525	4.1

Conductivity was then converted to salinity by formulas from
UNESCO/ICES/SCOR/IAPSO (1981).

3.4 Photosynthetically Available Radiation (PAR, Scalar Irradiance), and 683 nm Upward Vertical Radiance (Lu683)

Vpar was recorded in decimal numbers. Then PAR in μEinsteins/m^2/s was calculated from:

$$PAR = C / B * (A + Vpar)$$

The calibration coefficients were:

Table 6: PAR Sensor Calibration Coefficients

depth	SN	A x 10^5	B	C
30m	4292	-2.0	1	85.13
70m	4293	-6.0	12.5	73.26
90m	4294	-4.0	40	81.31

V683 was recorded in decimal numbers. Lu683 in μEinsteins/m^2/s/nm/str was calculated from:

```
Lu683 = C / B * (A + V683).
```

The calibration coefficients were:

Table 7: LU683 Sensor Calibration Coefficients

depth	SN	A x 10^4	B	C x 10^2
30m	7014	-4.0	350	2.176
70m	7015	-5.4	350	1.992
90m	7016	-5.1	350	1.973

3.5 Transmissometer

Transmissometer data were recorded in decimal numbers. The conversion from recorded voltage to percent transmittance (X%) was:

```
X% = 20*((A/B) * (VOLTS - Z)
```

Beam attenuation coefficient was calculated by:

```
b.a.c. = - ln(X%/100) / 0.25
```

where 0.25 is the pathlength in meters.

Table 8: Transmissometer Calibration Coefficients

depth	SN	A	B	Z
30m	380	4.826	4.735	0.003
70m	46D	4.73	4.716	0.002
90m	223	4.739	4.683	0.004

3.6 Dissolved Oxygen Sensor

Dissolved Oxygen was converted to physical units using the following procedure.

First step was to convert voltage (V) to current units:

$As = (CA + CB) * V$

The DO concentration (O2) in mmol/l was calculated as:

$O2 = Ss(T,S) * As/(OA+OB*T)$

where Ss is the solubility coefficient, dependent on VMCM temperature (T, in ^{o}C) and average salinity (S, in psu). Ss is given by equation:

$$Ss = Cstar/(0.20946*(101.325-pH_2O))$$

where

$$TK = T + 273.15$$

$$Cstar = \exp(A1+A2/TK+A3/TK^2+A4/TK^3+A\%/TK^4+S[A6+A7/TK+A8/TK^2])$$

$$pH_2O = \exp((-216961/TK-3840.7)/TK+16.4754$$

with
$A1 = -135.9025$
$A2 = 15750.1$
$A3 = -6.642308*10^7$
$A4 = 1.2438*10^{10}$
$A5 = -8.621949*10^{11}$
$A6 = 0.017674$
$A7 = -10.764$
$A8 = 2140.7$

and the values of the CA, CB, OA, OB listed in Table 9. The TK and pH_2O equations come from Benson and Krause (1984) and Gnaiger and Forsther (1983).

Table 9: Dissolved Oxygen Sensor Calibration Coefficients

depth	SN	CA	CB	OA	OB
30m	48	-0.041	0.011103	N.A.	N.A.
70m	49	-0.06	0.011081	N.A.	N.A.
90m	50	0.071	0.011094	2.218	0.023

3.7 VMCM data

VMCM data are the last part of the record. Those fields contain information on record count, north vector, east vector, rotor-2 counts, rotor-1 counts, compass value, and temperature. All data are recorded in hexadecimal characters. Each item is 4 characters long, except compass value, which is 2 characters long.

3.7.1 Current Vectors

Current vector components in engineering units were obtained from:

```
VE = K * VecE/t

VN = K * VecN/t
```

where K = 9.363 cm/count, VecE is the east-vector count, VecN is the north-vector count, and t is the averaging time interval in seconds.

To account for magnetic declination, currents were rotated -17.6° using following formula:.

```
new_VE = VN * cos(17.6°)- VE * sin(17.6°)
new_VN = VE * cos(17.6°) -VN * sin(17.6°)
```

3.7.2 VMCM temperature

VMCM temperature is discussed in Section 3.2.

4. REMARKS ON THE DATA

(1) Due to storage device problem, the following data are missing:

30m, between day 208.19 and day 238.06

90m, between day 208.02 and day 238.44.

(2) Due to an instrumentation problem at 70m, there are no data after day 182.02.

(3) Due rotor problem at 30 m, current velocities after day 190.62 are deleted.

(4) Due to compass problem at 90 m, current speed after day 122.70 are deleted.

(5) Due to sensor-gain problem, all upwelled radiance (Lu683) measurements are inadequate and not reported.

(6) Due to a connector failure, DOX at 30m and 70m are not available.

5. REFERENCES

Marra, J. and C. Langdon. 1993. Evaluation of an In situ fluorometer for the estimation of chlorophyll a. Lamont-Doherty Earth Observatory Technical Report LDEO-93-1, pp23+figs.

Unesco/ICES/SCOR/IAPSO, 1981, Background Papers and Supporting Data on the Practical Salinity Scale 1978, p. 141-144.

Benson,B. and D. Krause ,1984. The concentration and isotopic fractionationof oxygen dissolved in freshwater and seawater in equilibrium with the atmosphere. Limnol. Oceanogr. 29, 620-632

Gnaiger, E. and H. Forsther, (Eds.). 1983. Polarographic Oxygen Sensors. Springer-Verlag, New York, 370pp.

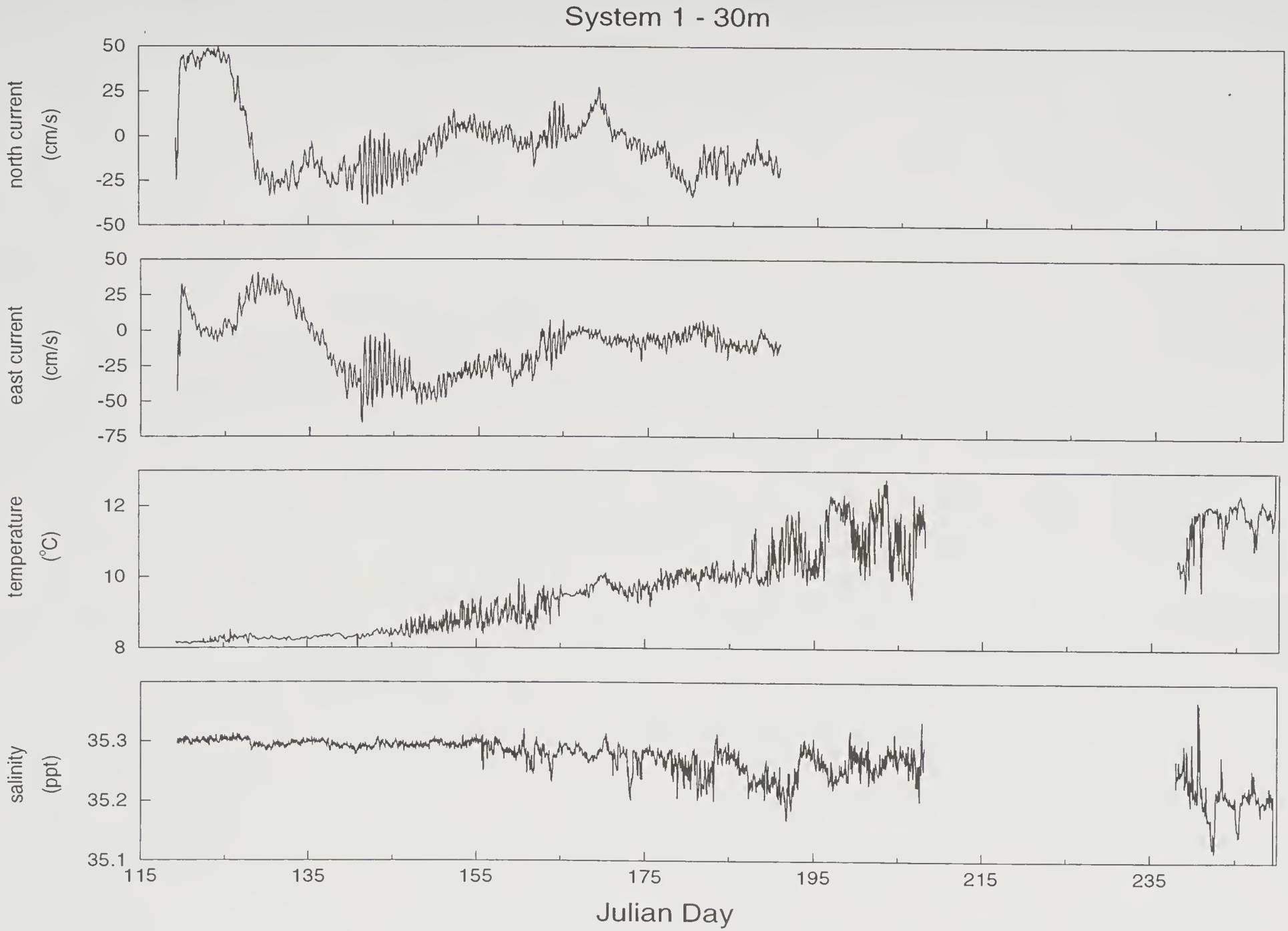
System 1 - 30m
north current (cm/s)
50
25
0
-25
-50
east current (cm/s)
50
25
0
-50
-75
temperature (°C)
12
10
8
salinity (ppt)
35.3
35.2
35.1
115
135
155
175
195
215
235
Julian Day

Fig.1

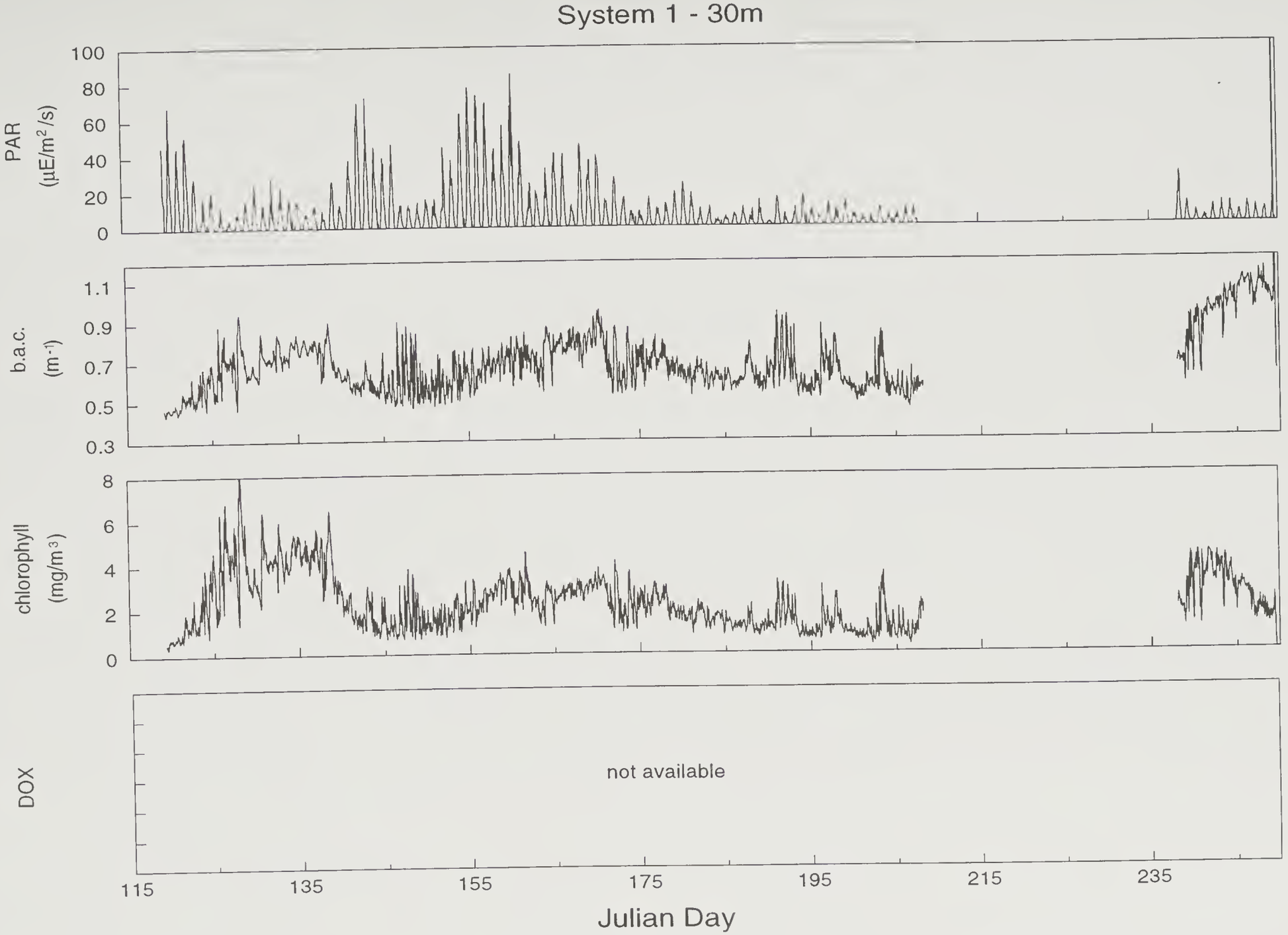
System 1 - 30m
PAR
(µE/m²/s)
100
80
60
40
20
0
b.a.c.
(m⁻¹)
1.1
0.9
0.7
0.5
0.3
chlorophyll
(mg/m³)
8
6
4
2
0
DOX
not available
115
135
155
175
195
215
235
Julian Day

Fig.2

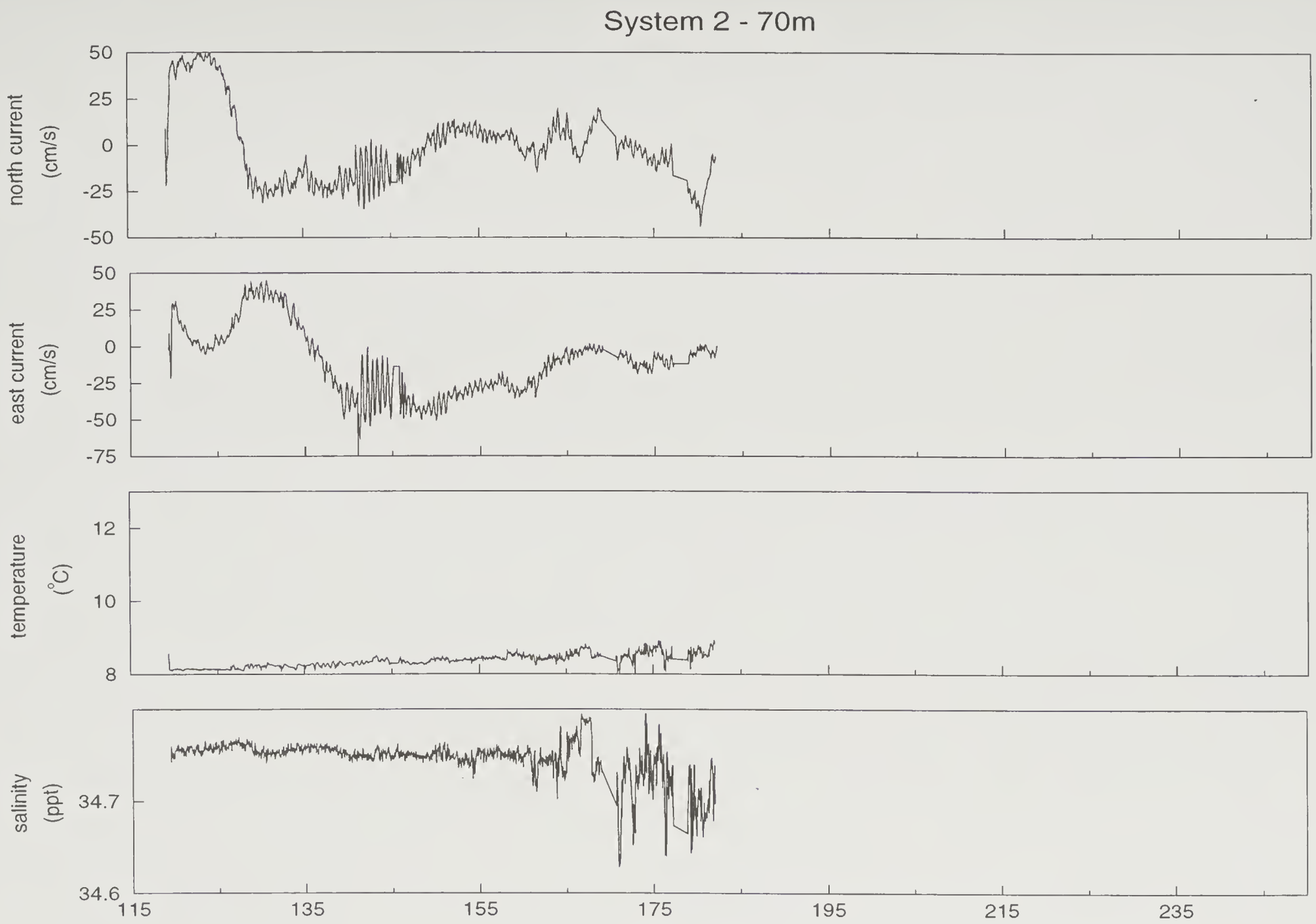
System 2 - 70m
north current (cm/s)
50
25
0
-25
-50
east current (cm/s)
50
25
0
-50
-75
temperature (°C)
12
10
8
salinity (ppt)
34.7
34.6
115
135
155
175
195
215
235
Julian Day

Fig.3

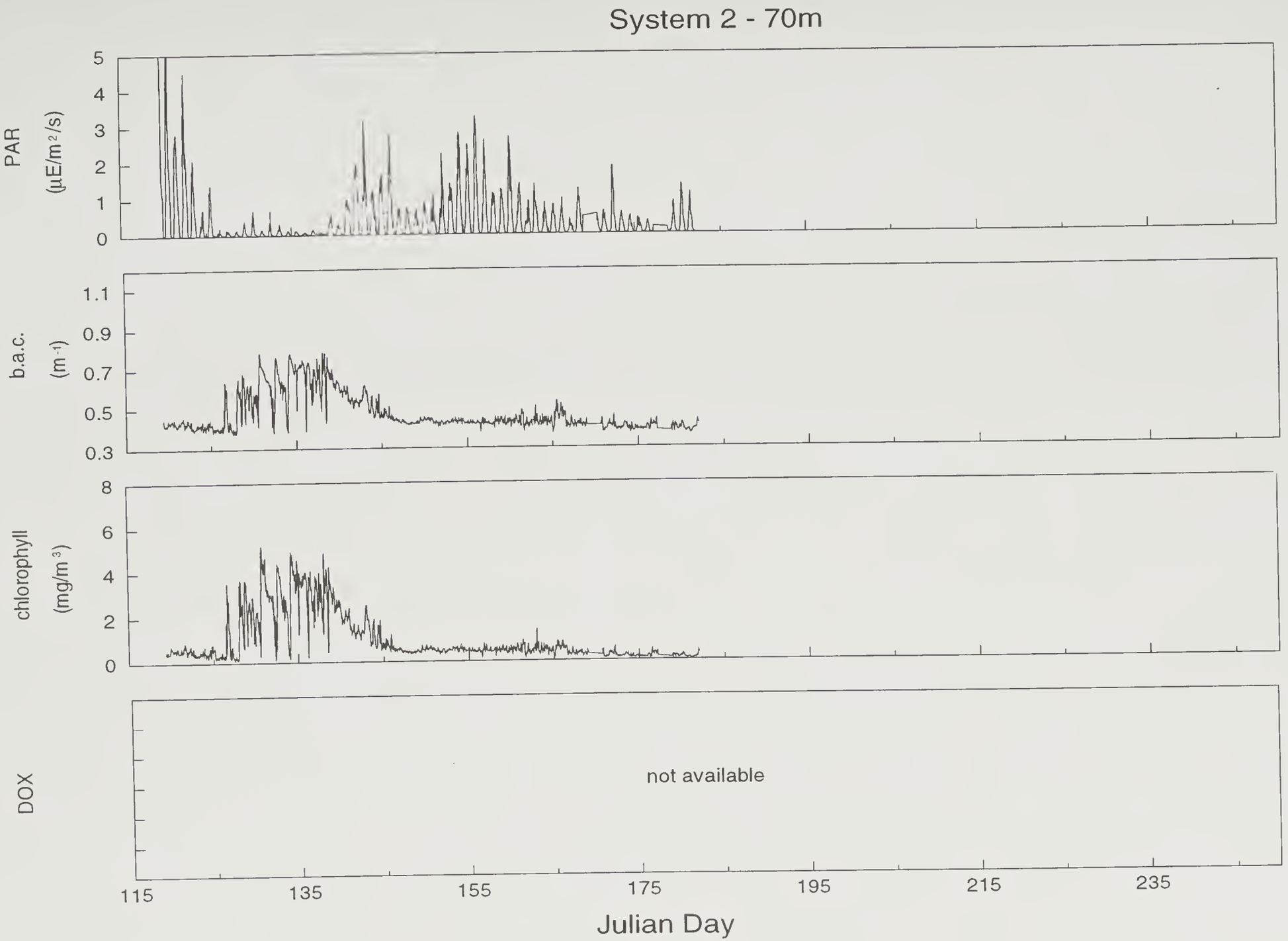
System 2 - 70m
PAR
(µE/m²/s)
5
4
3
2
1
0
b.a.c.
(m⁻¹)
1.1
0.9
0.7
0.5
0.3
chlorophyll
(mg/m³)
8
6
4
2
0
DOX
not available
115
135
155
175
195
215
235
Julian Day

Fig.4

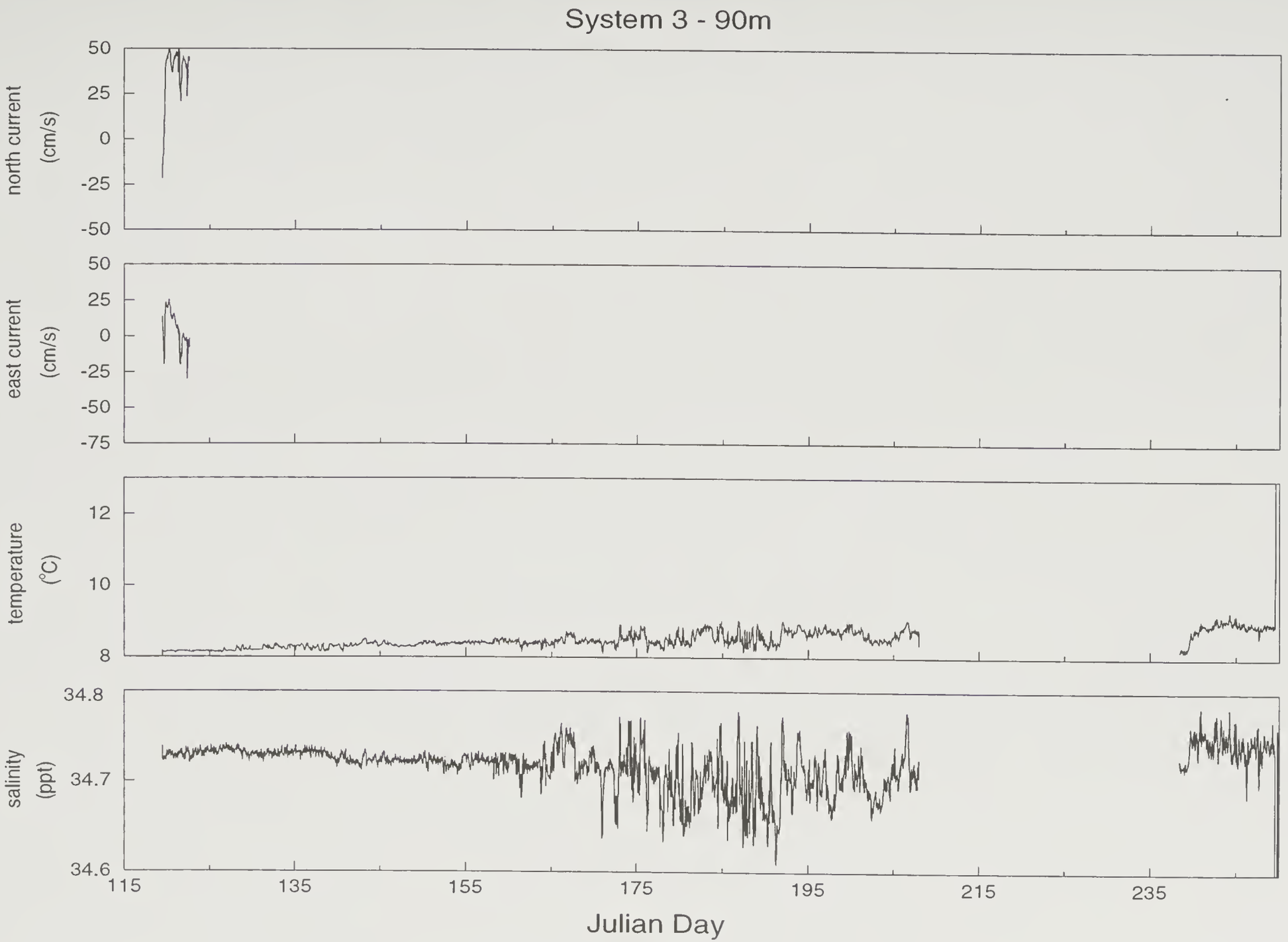
System 3 - 90m
north current (cm/s)
50
25
0
-25
-50
east current (cm/s)
50
25
0
-50
-75
temperature (°C)
12
10
8
salinity (ppt)
34.8
34.7
34.6
115
135
155
175
195
215
235
Julian Day

Fig.5

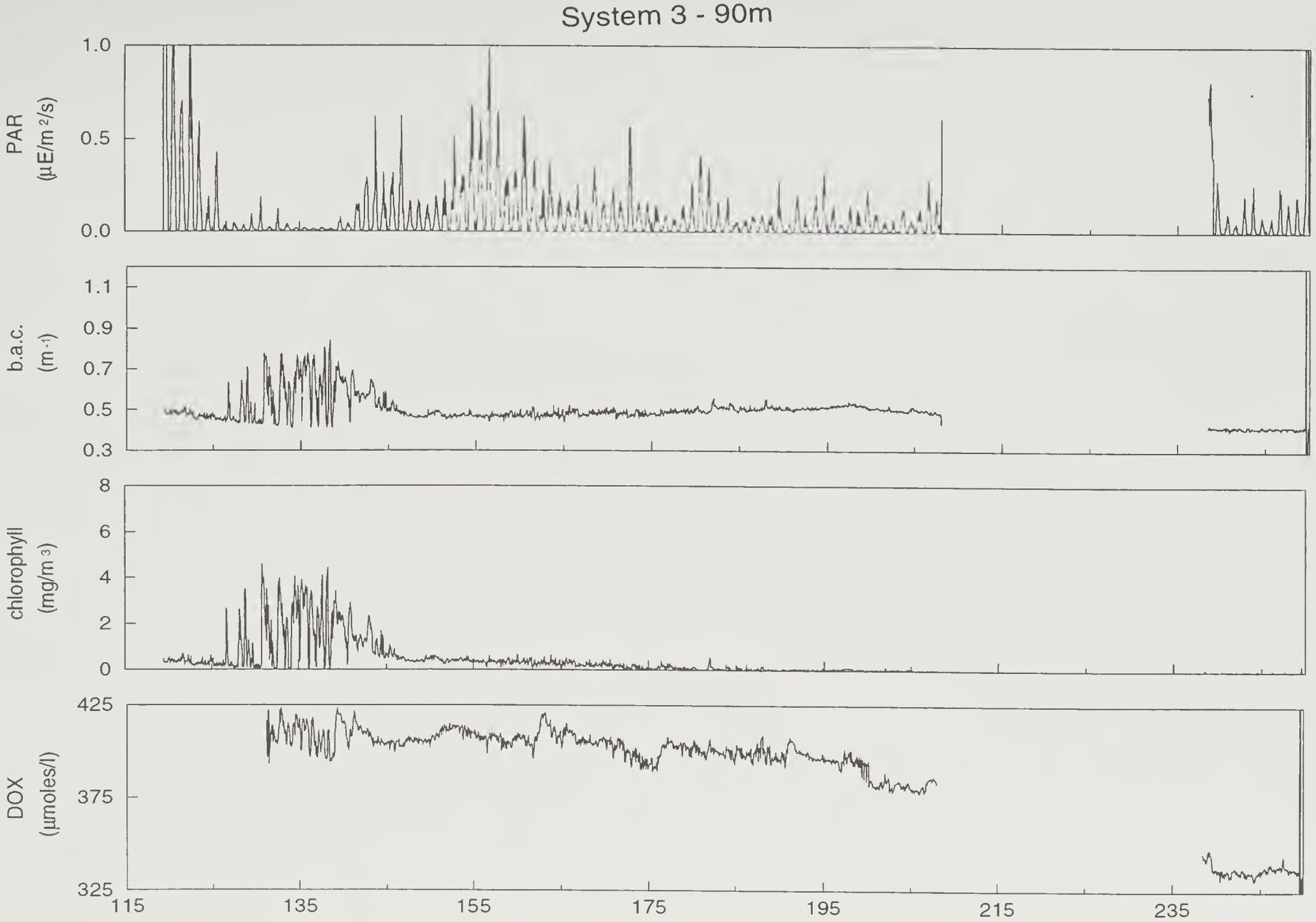
System 3 - 90m
PAR
(µE/m 2/s)
1.0
0.5
0.0
b.a.c.
(m-1)
1.1
0.9
0.7
0.5
0.3
chlorophyll
(mg/m 3)
8
6
4
2
0
DOX
(µmoles/l)
425
375
325
115
135
155
175
195
215
235
Julian Day

Fig.6

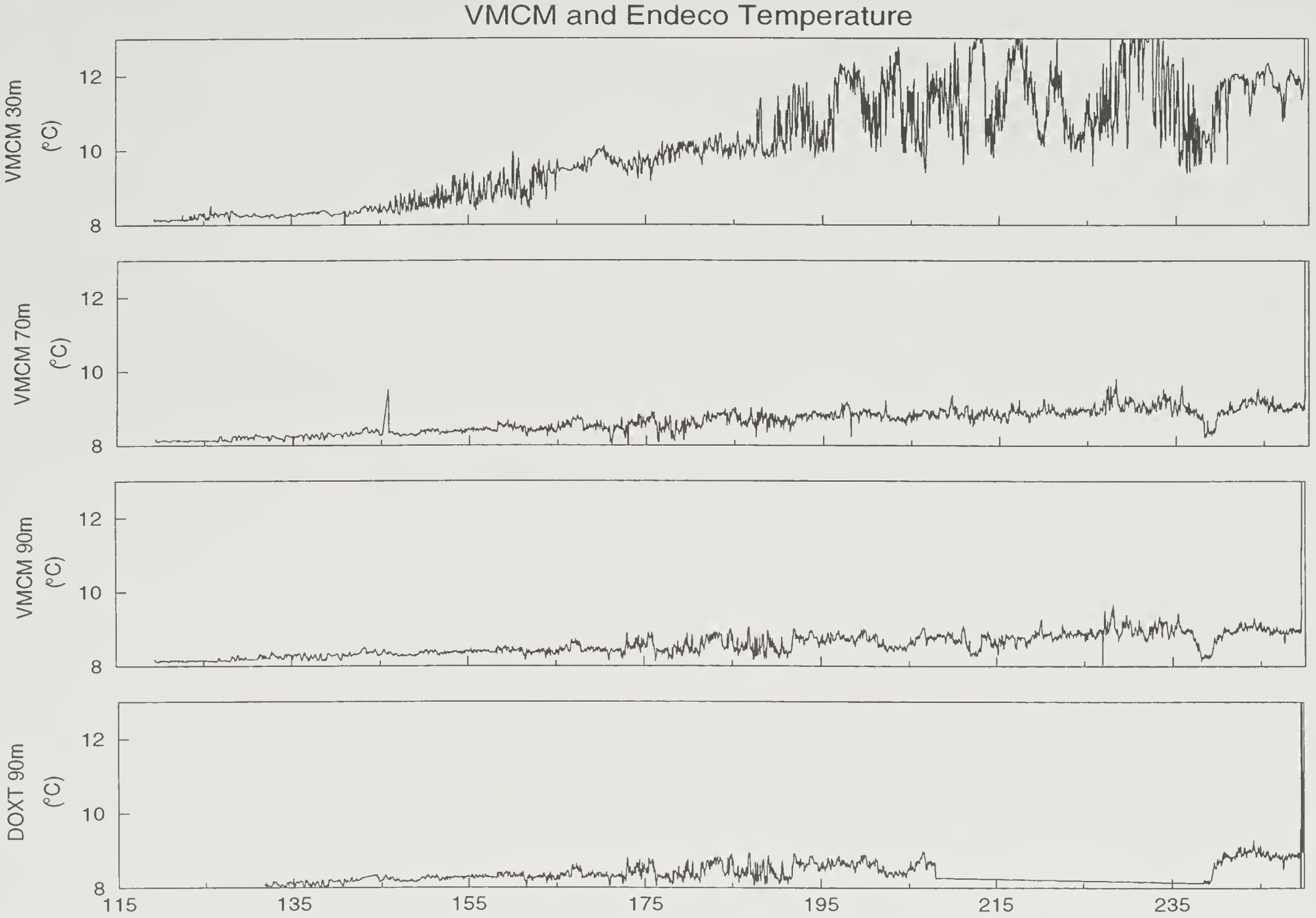
VMCM and Endeco Temperature
VMCM 30m
(°C)
VMCM 70m
(°C)
VMCM 90m
(°C)
DOXT 90m
(°C)
12
10
8
115
135
155
175
195
215
235
Julian Day

Fig.7

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13. ABSTRACT (Maximum 200 words)

Multi-variable moored system were used to collect physical and bio-optical data over a 130 days period in the North Atlantic Ocean (59°35.6'N/20°57.9'W) from Apr. 29,'91 to Sept.6,'91.We present data from MVMS', positioned at 30,70 and 90 m depth. Calibration and validation issues are considered in the presentation of data.

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